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# INTEGRATED METHODOLOGY FOR THE DESIGN AND PROCESS SIMULATION OF DIE CASTING

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# An Integrated Methodology for the Design and Process Simulation of Die Casting

by

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## ABSTRACT

A new conceptual approach to product design for die casting will be presented. Processing requirements as well as the effects of casting parameters on product performance will be discussed.

Typical applications of a new design analysis sequence will be shown through various steps: product definition, process analysis, material behavior, finite element modelling and evaluation of the finished product.

Realistic models can be optimized interactively, taking into consideration the material characteristics and properties under service conditions. A complete finite element analysis can be performed based on the information obtained from the filling and solidification analyses. Also, problems such as weld lines, shrinkage, porosity, orientation and other geometric discontinuities can be treated during the design optimization.

## 1 INTRODUCTION

The progress in materials technology is embodied in its continuing transition from an art to an engineering science. It depends also on other technological improvements in the areas of control systems, computer graphics, heat transfer, fluid dynamics, numerical analysis, etc.

An engineering simulation of materials behaviour is the key to automation without risk; it provides solutions that avoid expensive design errors during the product development cycle. Naturally, the engineering simulations are limited to problems that are understood well enough to be described with a mathematical modelling approach. A process simulation can describe the material behaviour under the operating conditions; this can be used to optimize the product and tool design, the production cycle, and the material usage. Also, process simulation might answer questions about manufacturing problems or the quality of the final product.

The research work described in this article should enlarge the technological perspective of die casting alloys and stimulate their introduction into more sophisticated products. A successful development of this technology will provide a competitive advantage to Canadian industry in the following fields: aerospace, appliance, automotive, construction, defence, electronic, medical and sports.

## 2 BENEFITS OF AN INTEGRATED APPROACH

There is a trend towards the integration of all the design and manufacturing steps, with the ability to simulate what is going on in a process, interpret it in the design phase of products and tools and forward the relevant information to the production equipment. Figure 1 is a block diagram of such a computer integrated die casting (C.I.D.C.) system. Figure 2 illustrates the importance of solid modelling technology in the application of such a system.

The part's requirements and the product design process must be well understood. Figure 3 shows the concept of part design optimization by considering the effects of material processing and service requirements. As shown in figure 4, extensive research is being done in this field at the Industrial Materials Research Institute, especially in the area of casting. The system captures the experience, knowledge and judgement of practitioners, combined with the mathematical modelling of the physical changes that occur during production and under service conditions.

A generic problem solving architecture has been designed and incorporated into the system. This decision making process is related to some concepts of acceptability. It implies the development of criteria based on engineering principles, material sciences and general practices of sound design for manufacturing. Furthermore, a compatibility with previous decisions must be maintained. In this context, the integration means a way to effectively chain together the interrelated technologies usually involved in casting, such as alloy metallurgy, mould design and manufacturing and material processing.

## 3 MODELLING OF PART GEOMETRY

The process begins with a three dimensional description of the object to be produced, as shown in figure 5. Modelling of a part geometry implies the use of material dependent design guidelines. At this step, a computerized material information system can assist the designer in the selection of the most appropriate metal alloy. This preliminary selection can be refined later on to meet other application requirements as described in the following sections.

In order to develop a reliable model, engineers must not only have access to a system that provides the correct existing values of material properties, but also the possible variations of these properties. The system includes several mathematical equations governing thermal, rheological and mechanical properties.

One can see a logical relationship between the major steps of a product development process and their associated materials databases. The type and duration of loading, the temperature range, and the environmental constraints under which the product operates have to be investigated. A preliminary structural analysis can then be performed to define the minimum thickness requirements; it may also reveal that the geometry requires more extensive modifications. This analysis can prevent serious design flaws and minimize the number of modifications during subsequent analyses.

## 4 DESIGN OPTIMIZATION BY PROCESS ANALYSIS

Mathematical models are being developed that will predict the behaviour of the material under the processing conditions. This includes the flow simulation of the molten metal into the mould cavities. These models will describe the melt flow pattern, pressure and temperature distributions and the melt characteristics such as viscosity, shear stress and orientation, based on the predicted flow regime (solid front or jetting).

Figure 6 shows the initial geometrical segmentation for the flow analysis as prepared from the boundary representation of the part. The flow front segmentation is developped iteratively during the filling analysis.

Possible weaknesses due to the formation of porosity, voids and weldlines can be avoided at this stage. Problem areas are highlighted by the software, facilitating the necessary modifications so as to properly fill the parts. Figure 7 shows the pressure drop and maximum melt velocity at the gate for different filling rates, as calculated by the simulation.

The effect of the loads imposed on the mould during casting must also be analysed. The mould's total deflection, a mould element's admissible deflection and required mould dimensions from predetermined deflections can all be calculated.

In addition, a parametric database is being developed for the most common feeding systems by taking into account the design and manufacturing guidelines, material characteristics and melt processing parameters. Interactive graphic menus assist in the design of sprue, runners and gates. A melt flow analysis can then be done on the feeding system; this is of particular value for

flow balancing in a multi-cavity mould. The solid model of the feeding system can be subtracted from the cavity plate to obtain the negative, as well as used in the calculation of waste material.

Part warpage due to differential cooling rates between neighbouring regions can be minimized by reducing the level of residual stresses. Analytical programs can be used to study the heat transfer that takes place between the part and the mould during the cooling phase. Figure 8 shows the basic shapes that are supported for the calculation of the cooling cycle.

During the solidification phase, the melt characteristics vary from point to point in the cavity. Since material shrinkage is not uniform in all directions, modifications of the cavity and core as well as longer mould debugging times are required to produce parts to specifications. A computerized shrinkage analysis capability will be developed at the Institute to overcome this problem. The designer will be able to take into account any differential shrinkage during the specification of manufacturing tolerances, especially for the critical dimensions.

The expert system provides the user with the recommended processing conditions, such as melt characteristics, mould temperature, clamping force, filling time and injection pressure. The designer can choose practical values to start the analysis and check if the results are within the limitations. Since the programs are interactive, a constant feedback is given at any step and the process simulation ends when the operating conditions have all been optimized.

## 5 DESIGN OPTIMIZATION BY PRODUCT PERFORMANCE ANALYSIS

The system also includes similar interactive programs to evaluate the mechanical stresses and strains induced during the forming process. These programs evaluate the effects of the clamping and ejection forces, pressure and thermal expansion on finished products. A typical application is presented in figure 9 for the design optimization of a box shaped experimental mould. These programs assist in the study of the following problems:

- Mechanical deflections
- Surface defects
- Crack propagation
- Flashes

The last step in the design optimization is an in depth finite element analysis. The results of the previous process oriented simulations, where the properties are variable and based on the actual casting conditions, are incorporated in the FEM analysis. The use of local material properties allows for the preparation of a more realistic model. This will make the analysis and interpretation of the results more reliable. Anisotropy, creep and fatigue behaviour can be investigated if the material properties are available in the database.

Figures 10 and 11 illustrate the importance of taking into account the influence of parameters such as weldlines, skin formation and temperature for a gear in comparison with a conventional analysis.

## 6 CONCLUSIONS

This article has shown new design and analysis capabilities centered around solid modelling technology. It incorporates procedures to address every facet of the product development cycle never before available in any CAD/CAM/CAE system. Partial solutions are not effective. Achieving a good level of integration requires a good understanding of the manufacturing technologies. The implementation of this technology can improve the working procedures and streamline the flow of information during the product development cycle. Also, we have seen the advantages of using some interrelated technologies, such as filling and cooling simulations, finite element modelling and material engineering, during the design phase of die cast products.

**BIOGRAPHY**

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Louis Paul Hébert received his Bachelor of Arts and Sciences in Honours Physics from Queen's University at Kingston, Ontario, Canada, in 1978. He completed a Master of Applied Science at the Institute of Aerospace Studies of the University of Toronto, Toronto, Ontario, in 1980. In 1981, he began working for the National Research Council Canada at the Industrial Materials Research Institute near Montreal. He is presently a member of the Computer Aided Design and Manufacturing Group.

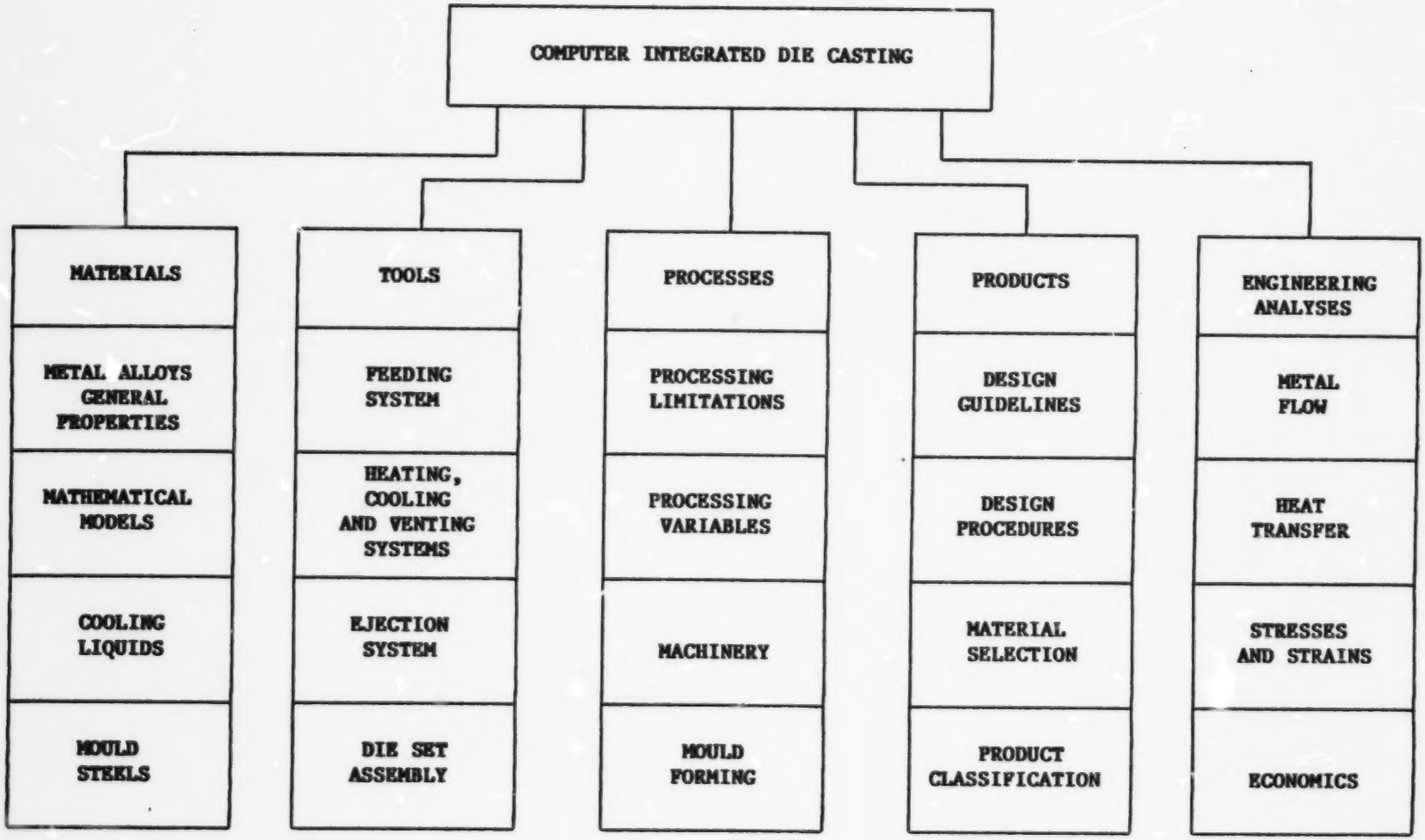



Fig. 1: COMPUTER INTEGRATED DIE CASTING

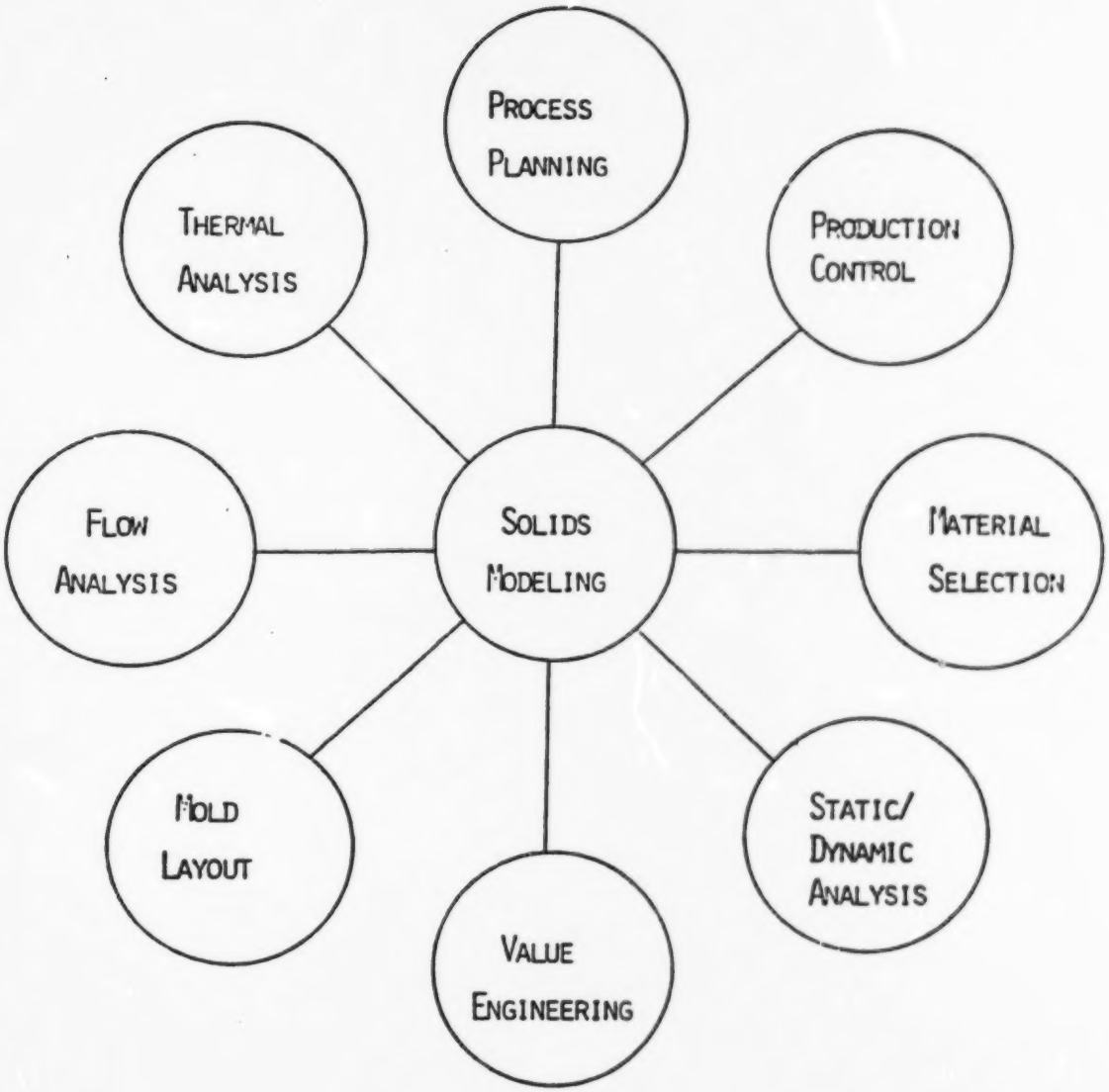



Fig. 2: COMPUTER INTEGRATED PRODUCT DEVELOPMENT PROCESS

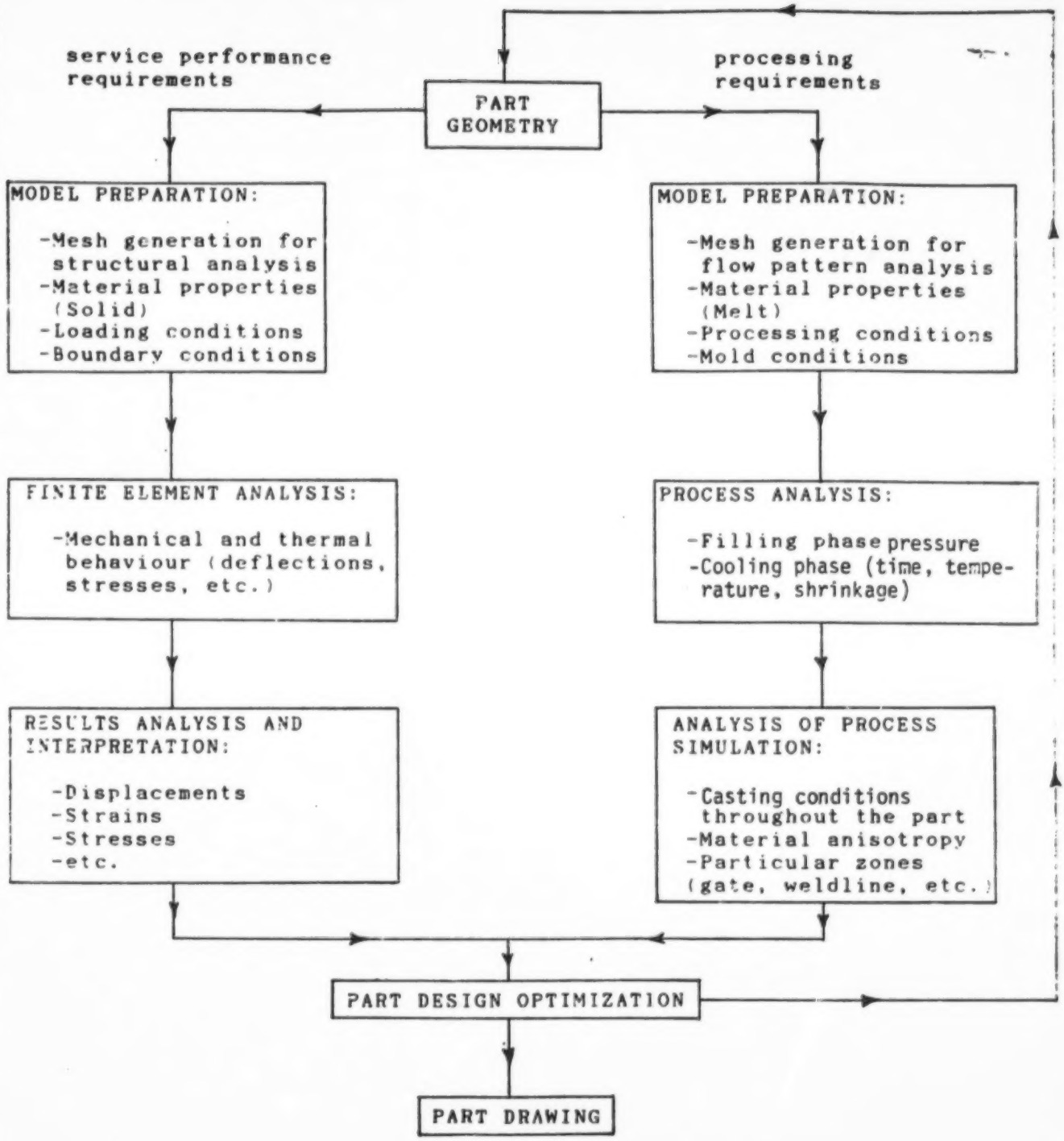



Fig.3 . PART DESIGN OPTIMIZATION BY CONSIDERING THE EFFECTS OF MATERIAL PROCESSING AND SERVICE REQUIREMENTS

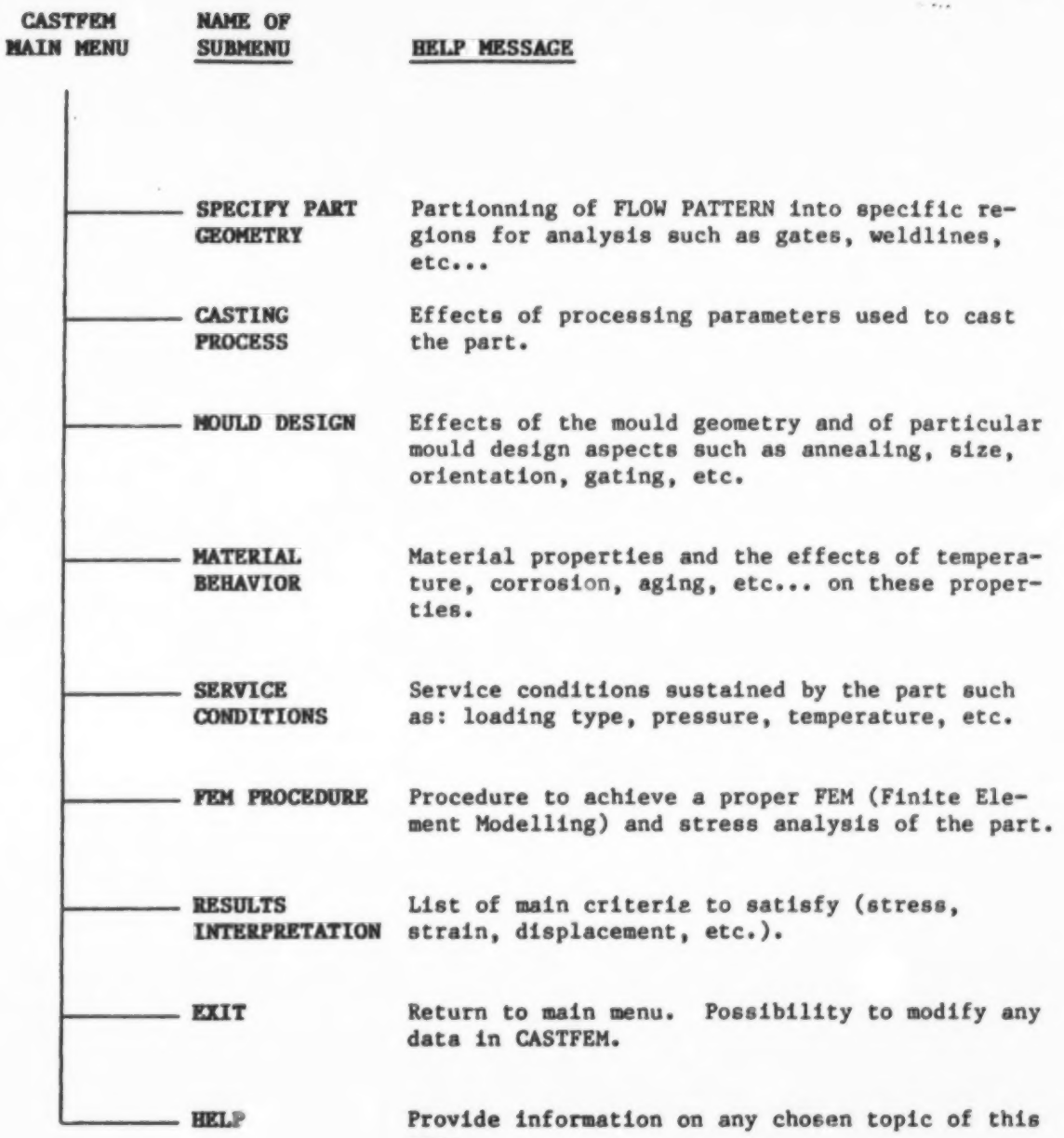

CASTFEM MAIN MENU
NAME OF SUBMENU
HELP MESSAGE
SPECIFY PART GEOMETRY
Partionning of FLOW PATTERN into specific regions for analysis such as gates, weldlines, etc...
CASTING PROCESS
Effects of processing parameters used to cast the part.
MOULD DESIGN
Effects of the mould geometry and of particular mould design aspects such as annealing, size, orientation, gating, etc.
MATERIAL BEHAVIOR
Material properties and the effects of temperature, corrosion, aging, etc... on these properties.
SERVICE CONDITIONS
Service conditions sustained by the part such as: loading type, pressure, temperature, etc.
FEM PROCEDURE
Procedure to achieve a proper FEM (Finite Element Modelling) and stress analysis of the part.
RESULTS INTERPRETATION
List of main criteria to satisfy (stress, strain, displacement, etc.).
EXIT
Return to main menu. Possibility to modify any data in CASTFEM.
HELP
Provide information on any chosen topic of this menu.

**Fig. 4: EXPERT-SYSTEM FOR THE DESIGN ANALYSIS OF DIE CASTED PRODUCTS**

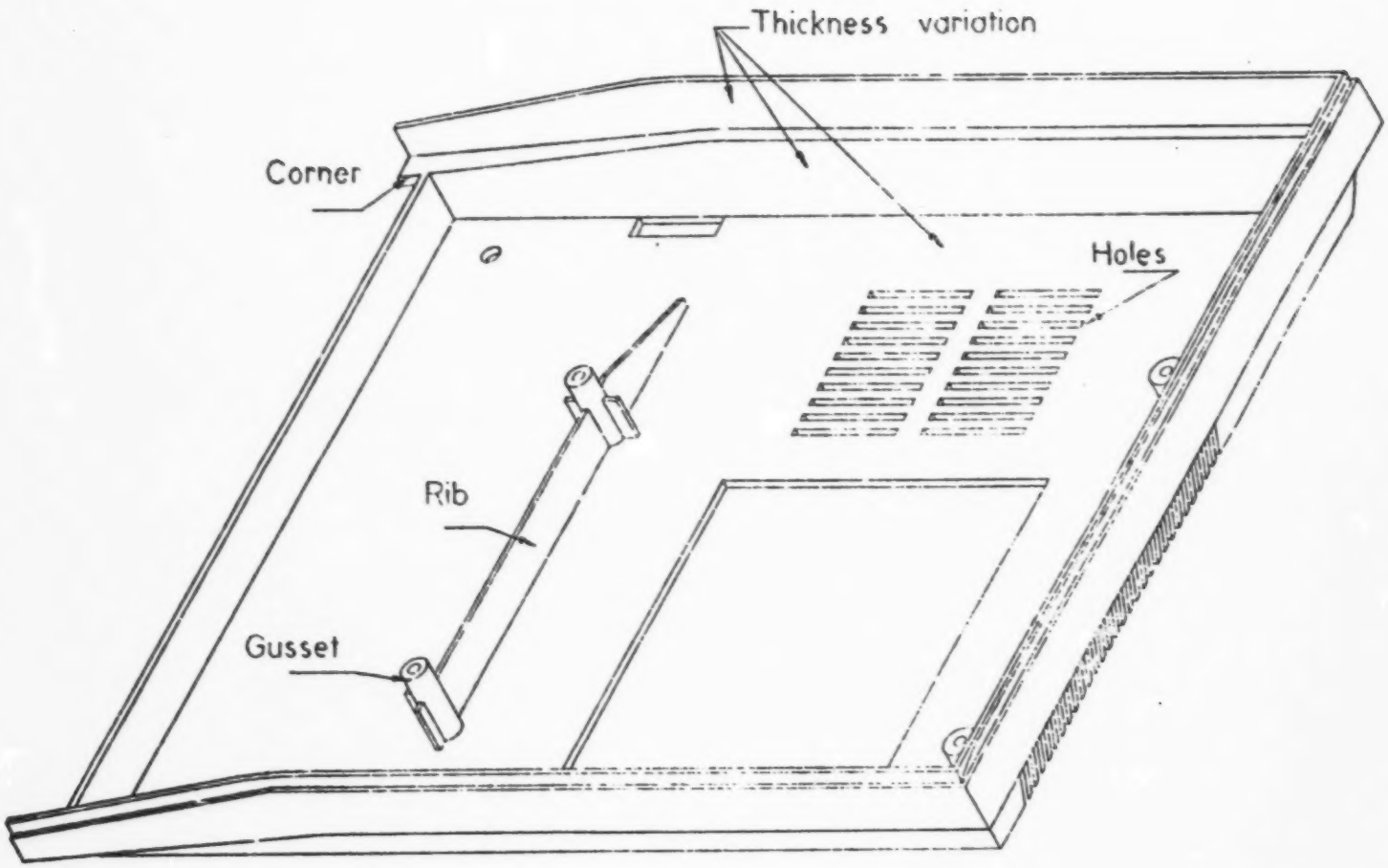



Fig. 5: 3D Solid Model

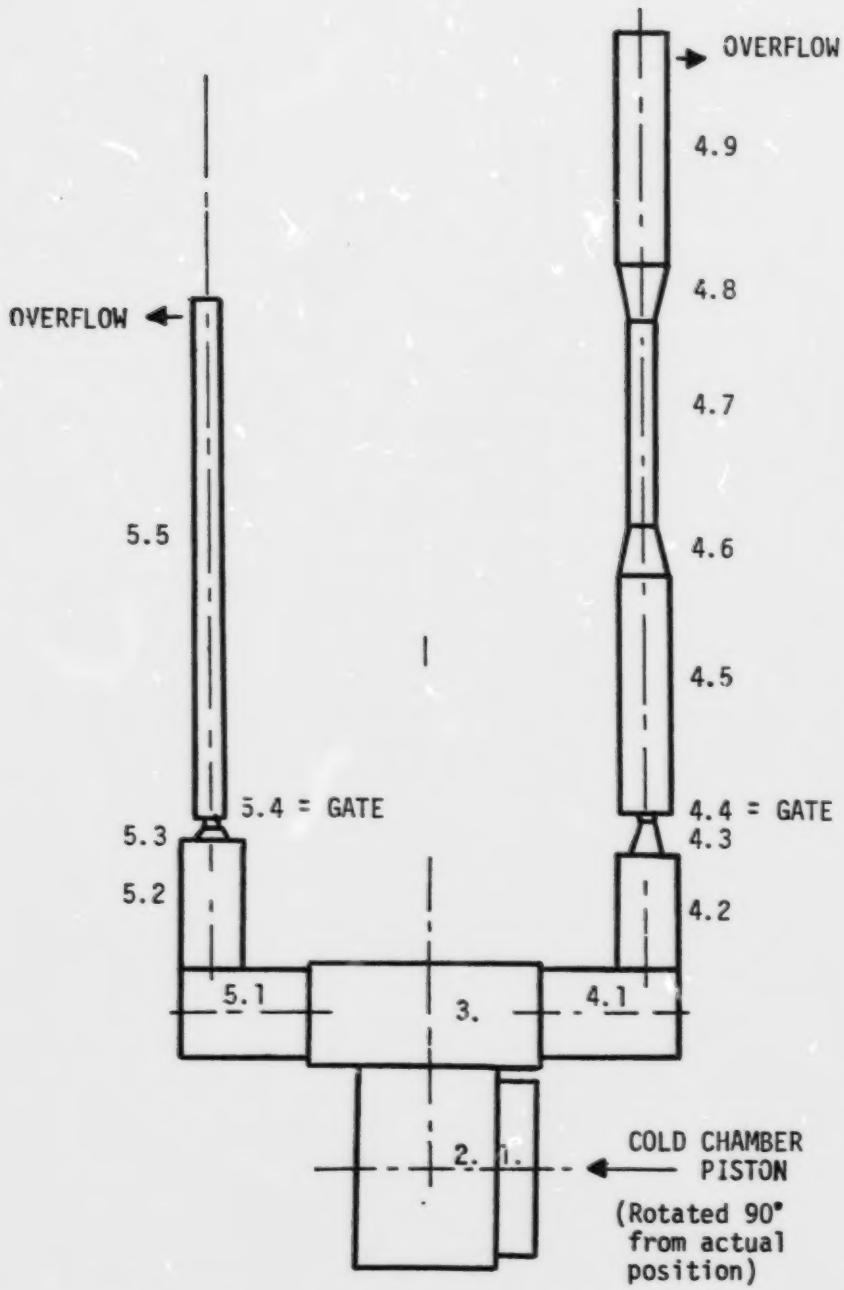



Fig. 6: Geometrical Segmentation for the Filling Phase

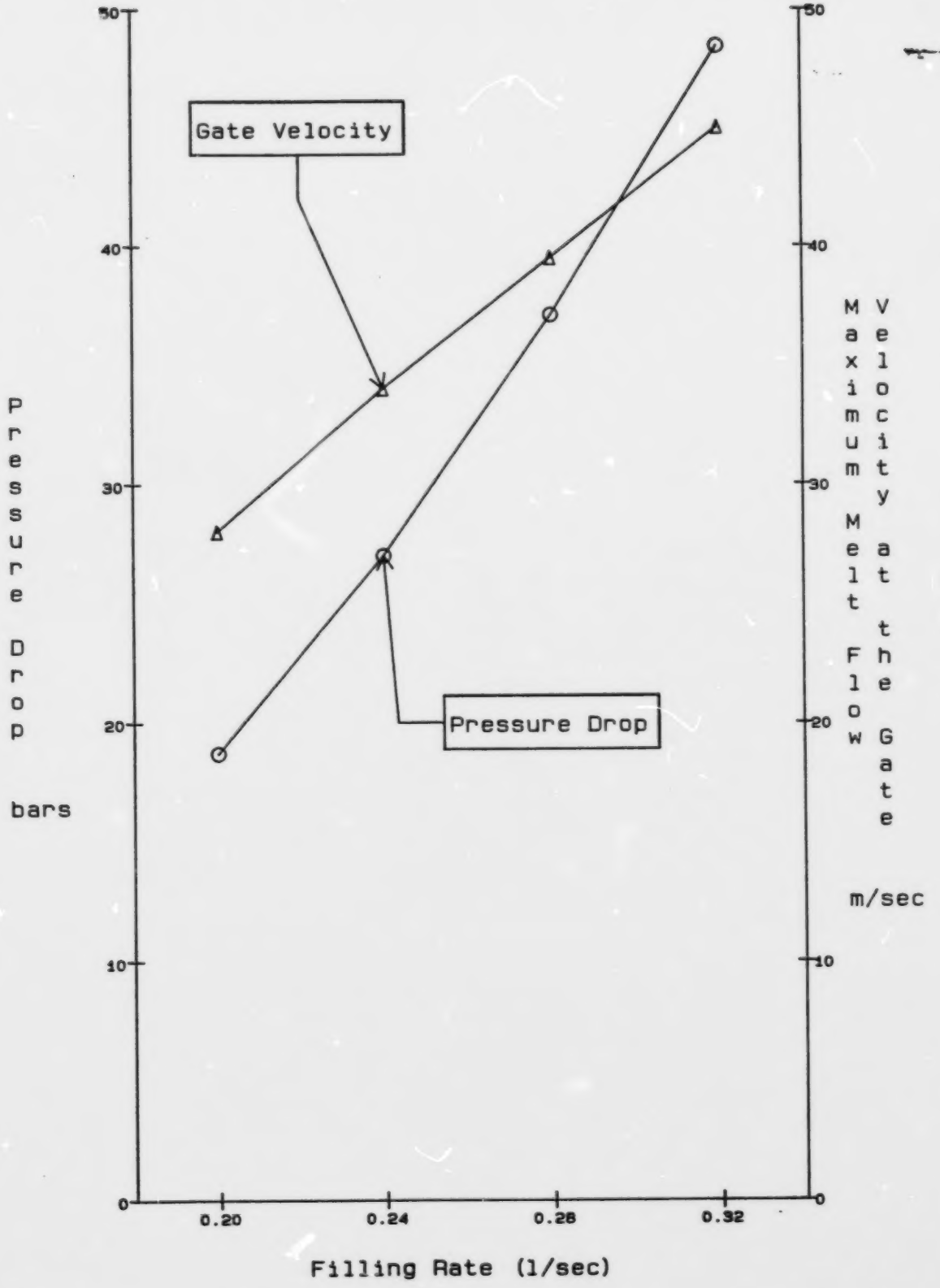
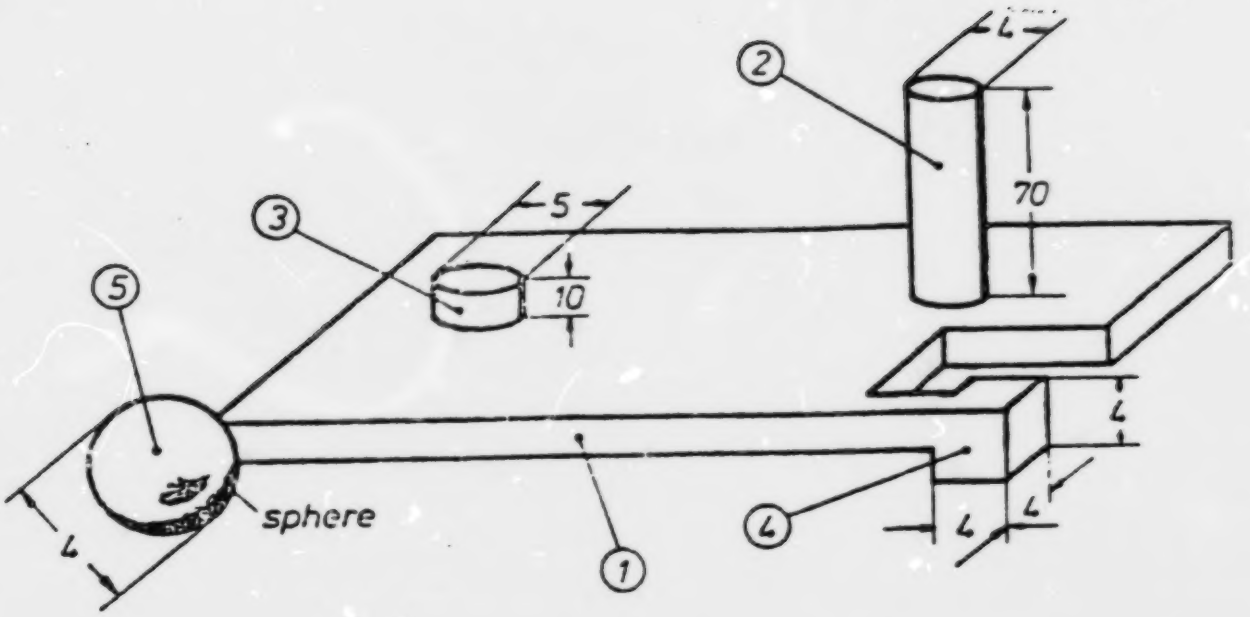



Fig. 7: Results of Mould Filling Simulation




- 1: Plate
- 2: Long Cylinder
- 3: Short Cylinder
- 4: Cube
- 5: Sphere

**Fig. 8 : Primitive geometries for the cooling time analysis**

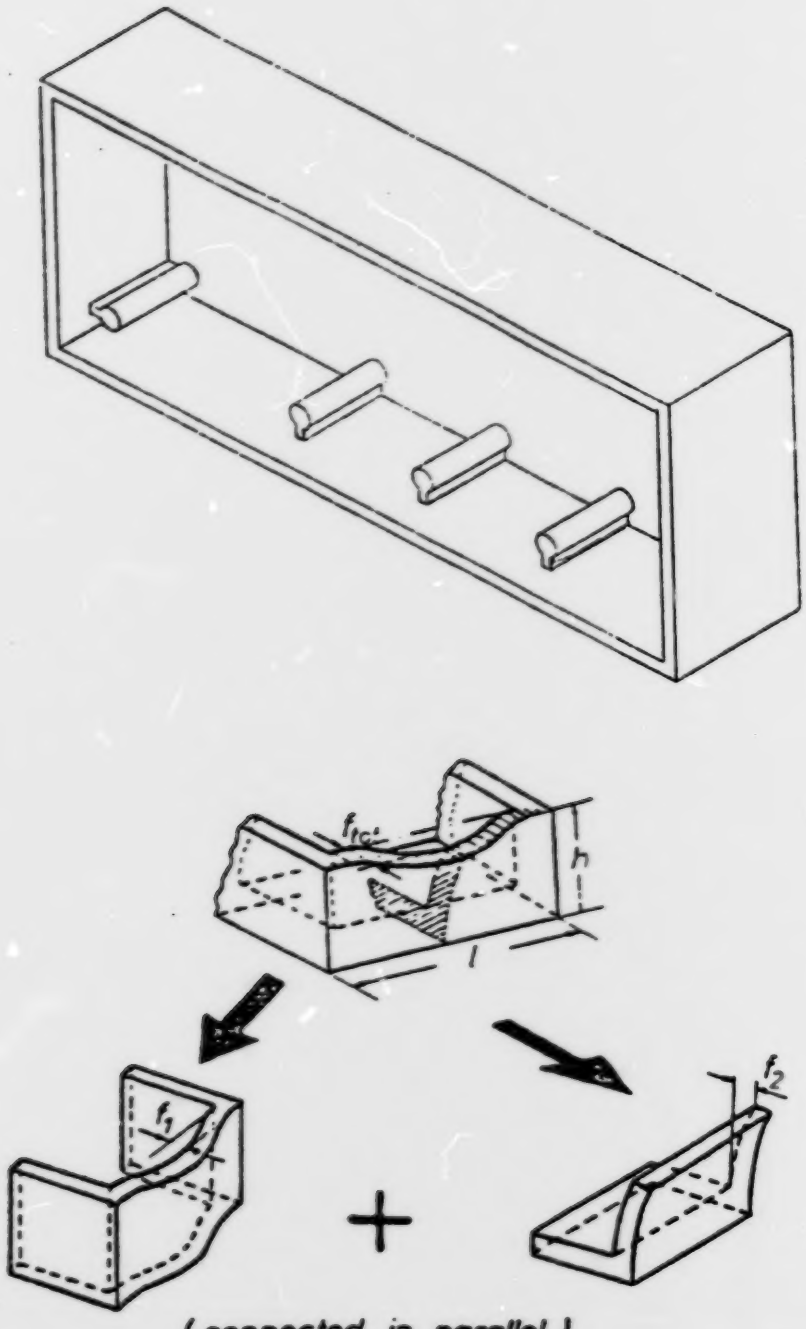
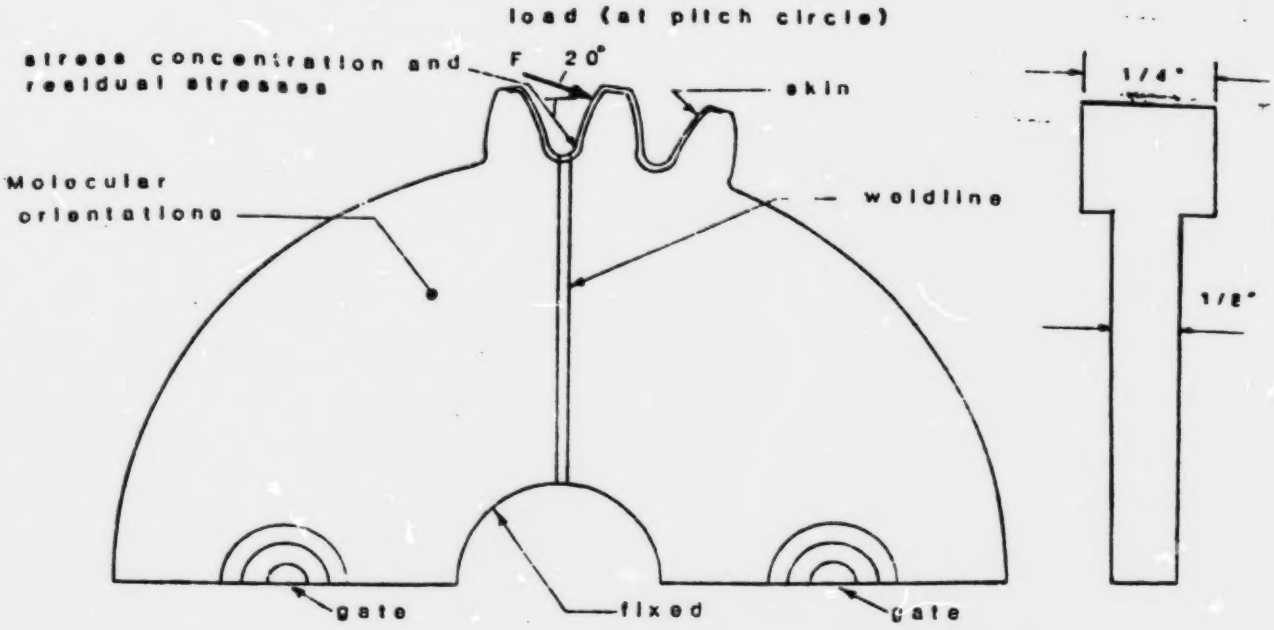
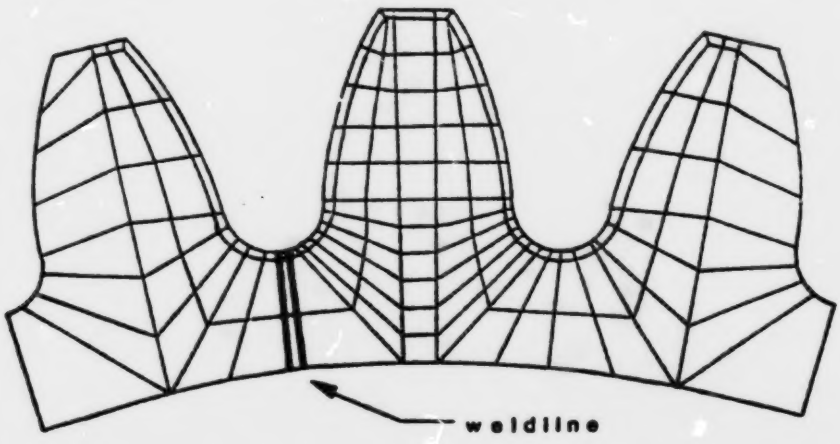



Fig. 9: Design Optimization of a Box Shaped Experimental Mould




a) Boundary conditions - Loading and Particular regions




b) Finite element meshing - tooth part

Fig. 10: Modelling of a gear for finite element analysis

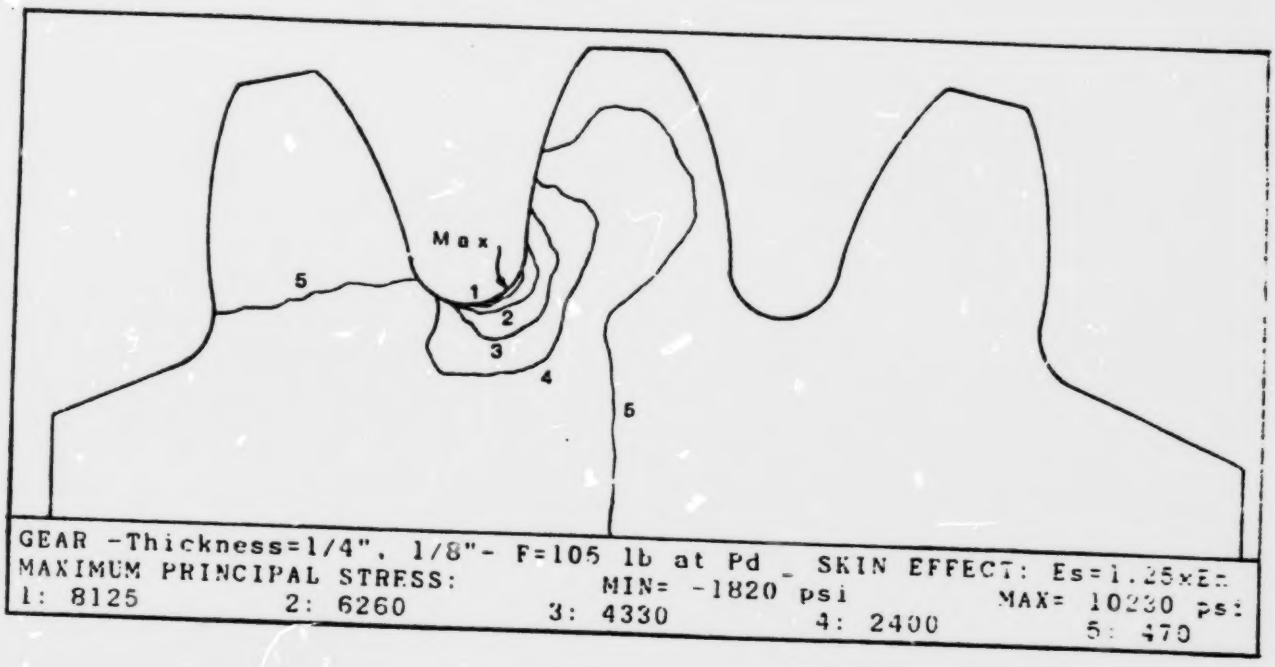



Fig. 11: Maximum principal stress distribution